TALE - 2 Course Design and Instruction of Engineering Courses
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Lecture - 33
Instruction for Design

Greetings, welcome to Module 3, Unit 15 - Instruction for Design thinking. In the earlier unit we saw, the simulation approach to instruction.

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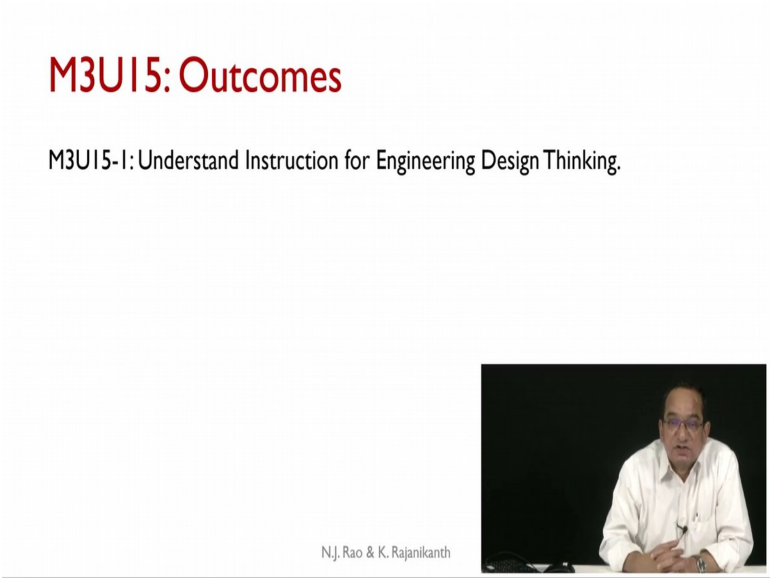

In this unit we will understand instruction for engineering design thinking.

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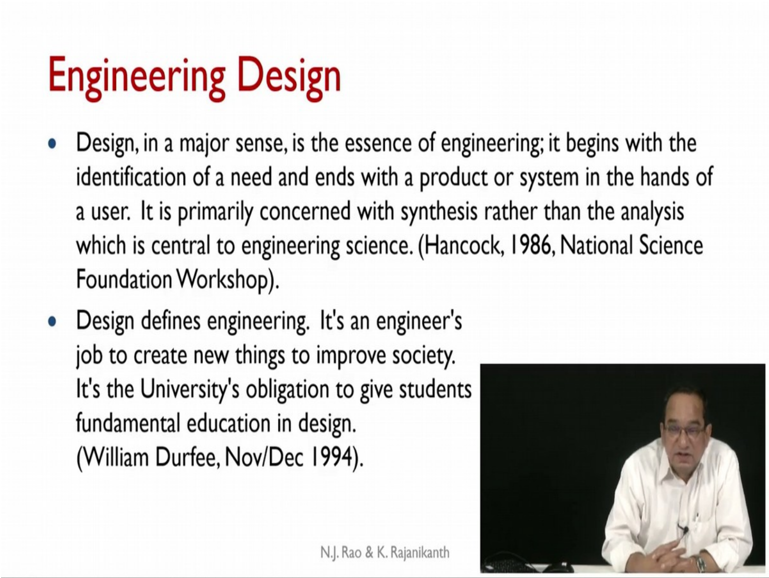

Design, in a major sense, is the essence of engineering. The design begins with identification of a need and ends with the product or system in the hands of a user. It is primarily concerned with synthesis rather than analysis, which is central to engineering science, this is one popular definition.

Another definition is: design defines engineering. It is an engineer’s job to create new things to improve society. It is the university’s obligation to give students fundamental education in design. We should not only teach core engineering science courses which focus on analysis, but we should also train the students well in engineering design which is a synthesis activity.

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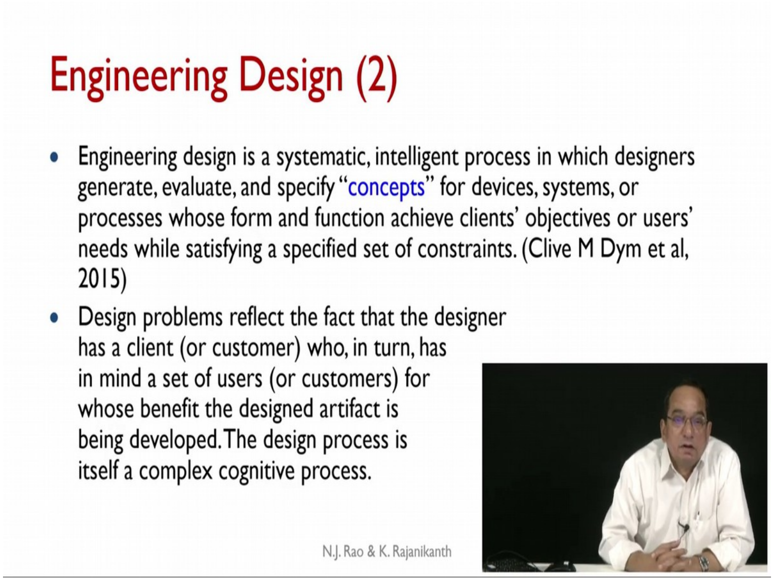

Another popular approach to the definition of engineering design: Engineering design is a systematic, intelligent process in which designers generate, evaluate and specify concepts for devices, systems, or processes whose form and function achieve clients' objectives or users needs while satisfying a specified set of constraints. Looks slightly elaborate, but it captures the essence of engineering design. And notice that he uses the word "concept" in a slightly different way than what we generally use as per Bloom's taxonomy.

What he generally means by concepts in this context is to specify the functionality or to specify the use to which the device or system is to be put. So, design problems reflect the fact that the designer has a client or a customer, who in turn has in mind a set of ultimate users who can be called as customers; for whose benefit the design artifact is being developed. The design process itself is a complex cognitive process.

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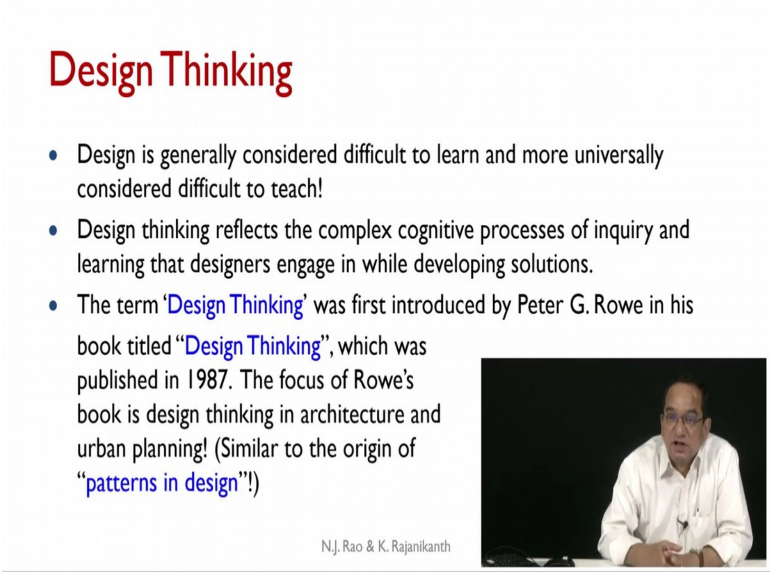

Design is generally considered difficult to learn and more universally considered difficult to teach. Design thinking reflects the complex cognitive process of inquiry and learning that designers engage in while developing the solutions. So, design is the actual process of creating the artifact and the design thinking is the cognitive process, which goes through in the minds of the designers

The term "design thinking" was first introduced by Peter Rowe in his book titled "Design Thinking" which was published in 1987. The focus of his book is design thinking in architecture and urban planning, quite similar to the origin of patterns in design. The patterns in design also arose in the context of architecture, but subsequently have become very popular in computer science, information technology and related areas. Similarly, the term design thinking arose in the context of architecture and urban planning, but now it is very popularly used in the entire engineering community.

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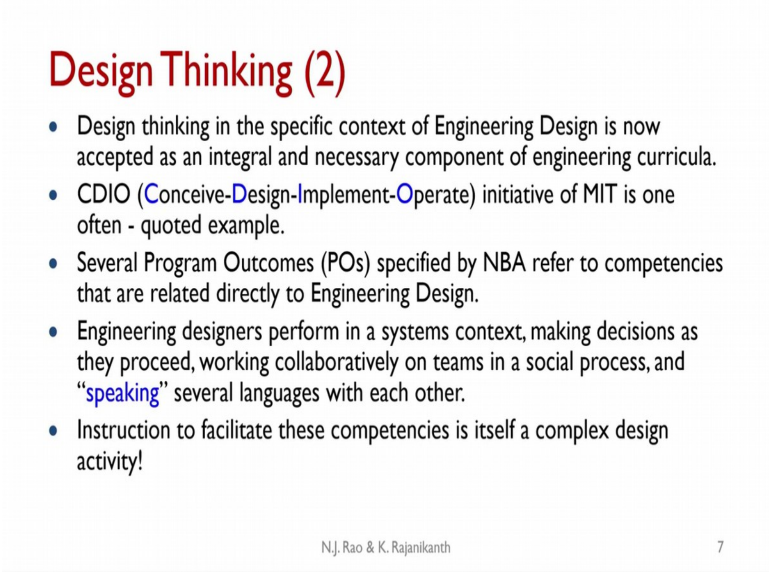

Design thinking in the specific context of engineering design is now accepted as an integral and necessary component of engineering curricula. The CDIO (conceive, design, implement, operate) initiative of MIT is one often quoted example. The d-School of Stanford University is also mentioned, but that was not specifically in the context of undergraduate engineering curricula.

Several program outcomes specified by NBA refer to competencies that are related directly to engineering design. Engineering designers perform in a systems context, making decisions as they proceed, working collaboratively on teams in a social process and speaking several languages with each other (these are the design languages). Instruction to facilitate these competencies itself is a very complex design activity; we can say it is the instructional design activity.

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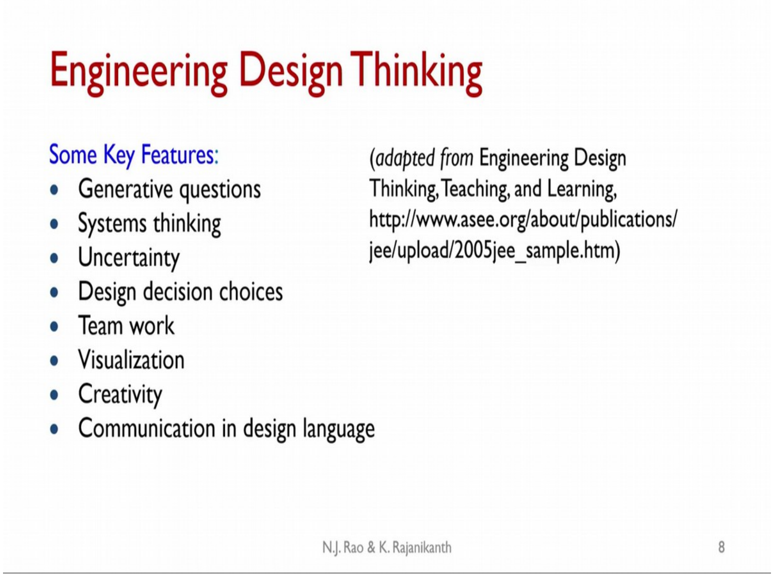

Engineering design thinking - some key features, adapted from the reference "Engineering Design Thinking, Teaching, and Learning," http://www.asee.org/about/publications/jee/upload/2005jee_sample.htm - are:

Generative questions - we look briefly at all these issues -, systems thinking, uncertainty, design decision choices, teamwork, visualization, creativity, communication in design languages.

Instruction for design thinking must address all these issues and train the students in all of these issues.

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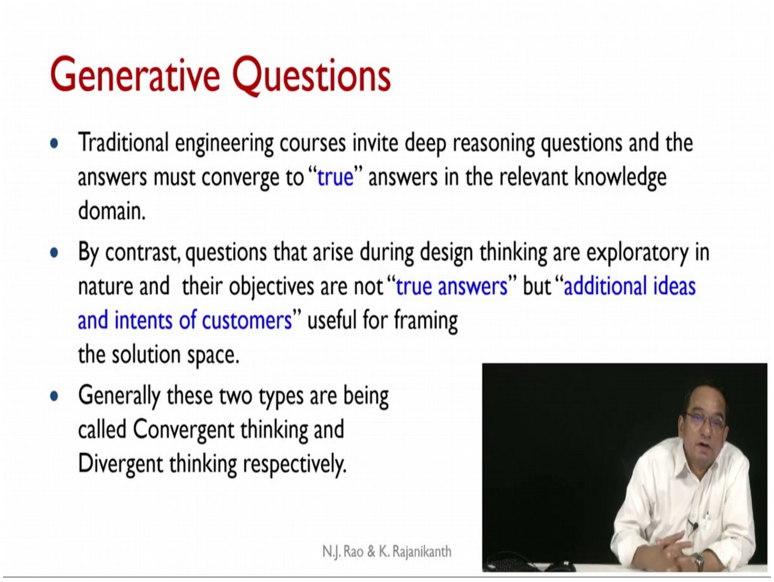

The traditional engineering courses invite deep reasoning questions, but the answers must converge to 'true' answers in the relevant knowledge domain. That means, the object of the question is to arrive at the true or correct answer.

By contrast - questions that arise during design thinking are exploratory in nature and their objectives are not true answers in the sense of reaching some well defined correct true answers; but additional ideas and intents of customers useful for framing the solution space. It is more a process of eliciting the requirements or the implicit needs or the intentions of the customers. They are more generative in nature and there is nothing like a true answer; but they are exploratory in nature.

Generally these two types of questions are being called as convergent thinking and divergent thinking respectively. Most of the engineering curricula, really train the students in convergent thinking.

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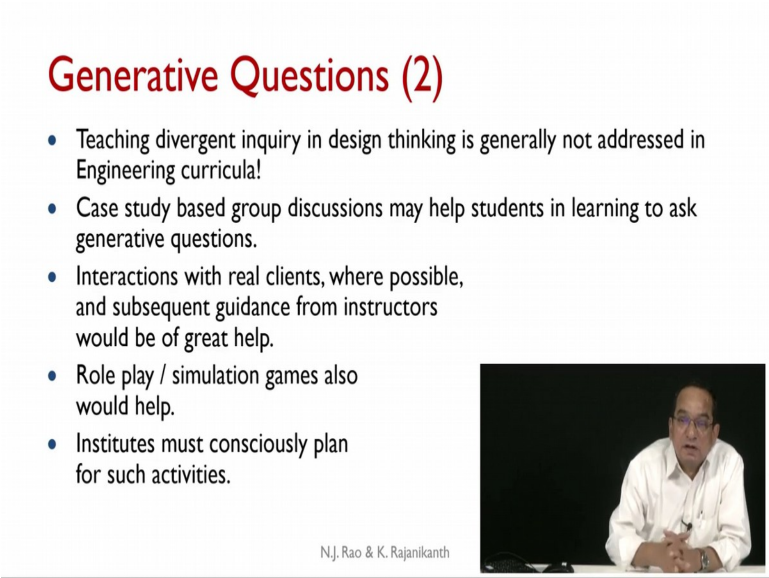

Teaching divergent inquiry in design thinking is generally not addressed in engineering curricula. Case study based group discussions may help students in learning to ask generative questions. Explicit training is required to make the students, understand the importance and develop the capability to ask the generative questions. Interactions with real clients where possible and subsequent guidance from instructor would be of great help. Role play, simulation games also would definitely help.

Institutes must consciously plan for such activities, because the regular courses focus only on convergent questions, convergent thinking. And, divergent thinking, generative questions need special focus, special attention if students have to acquire those competencies.

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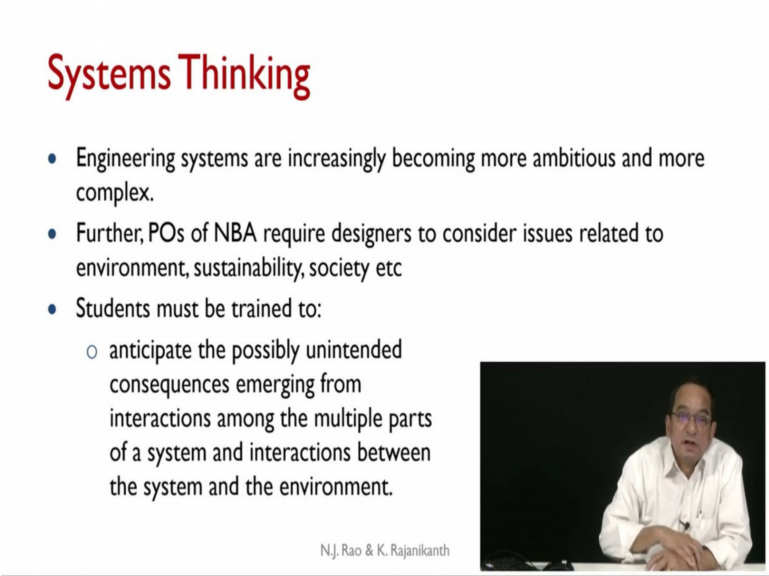

Engineering systems are increasingly becoming more ambitious and more complex. As the capabilities increase, as the technologies become more sophisticated, as the ambitions of customers become more sophisticated, the systems also tend to become more complex. Further POs of NBA require designers to consider issues related to environment, sustainability, society, legal issues and so on.

Students must be trained to anticipate the possibly unintended consequences emerging from interactions among the multiple parts of a system and interactions between the system and the environment. When many parts are put together, the resulting complexity can lead to results which are unintended; the consequences are unintended. They can arise either from interactions among the components, subsystems themselves or the interactions between the system and the environment.

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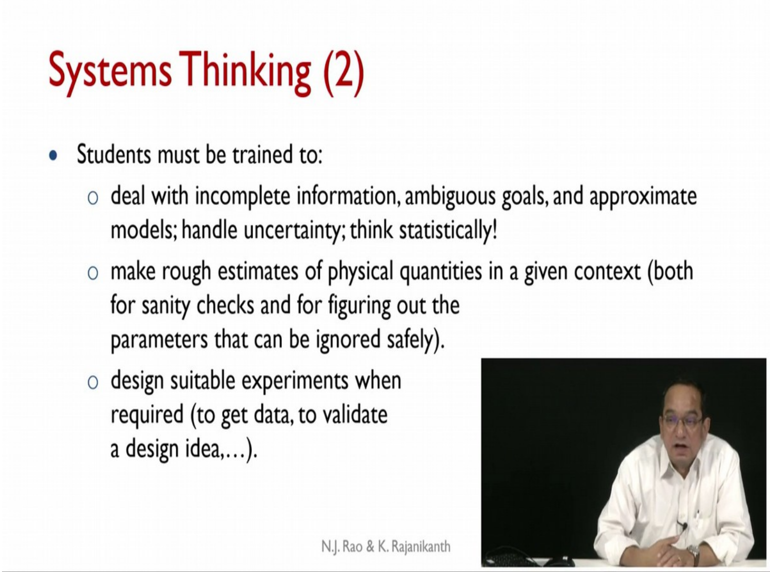

They must be trained to deal with incomplete information, which is typically the case in any real world problem; ambiguous goals (customers often are not very clear what is it that they exactly want) and approximate models (almost every model that we create during the design is an approximation to the reality, so approximate models); handle uncertainty; and think statistically; make rough estimates of physical quantities in a given context - and this is required both for sanity checks of the design and for figuring out the parameters that can be ignored safely. Usually a complex system will have too many parameters and it will be humanly almost impossible for the design team to take care of all the parameters. So, often we make rough estimates of the physical quantities involved and make a judgment as to which parameters can be safely ignored in the subsequent design process. This is also a skill that we must consciously impart to the students.

The students must be trained to design suitable experiments when required to, to get additional data, to validate a design idea, to make some of the requirements more clear - there are several contexts why we may have to do some suitable experiments. So, how to design suitable experiments also must be taught to the students.

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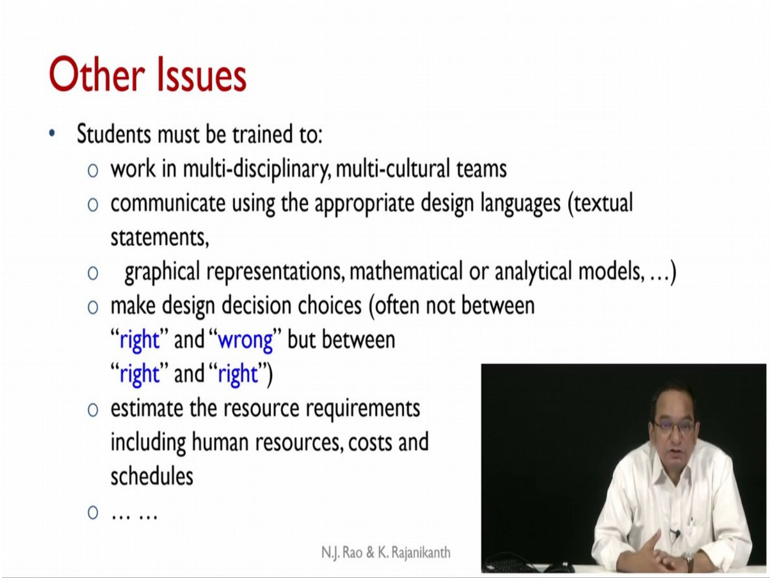

Students must be trained to work in multi-disciplinary, multi-cultural teams (another PO states this requirement also). Communicate using the appropriate design languages. They can be textual statements, graphical representations, mathematical or analytical models or languages which are very specific and unique to a particular domain. So, they must use appropriate design languages.

Make design decision choices and most of the times they are not between right and wrong, but between right and right! Both the choices are right, but you have to decide which one is a better choice. Better may be in terms of efficiency, in terms of cost, in terms of time to market, in terms of usability - there could be several parameters. Essentially both are right, but designers must choose one among them and this kind of thinking also requires very specific training. Estimate the resource requirements including human resources, costs and schedules.

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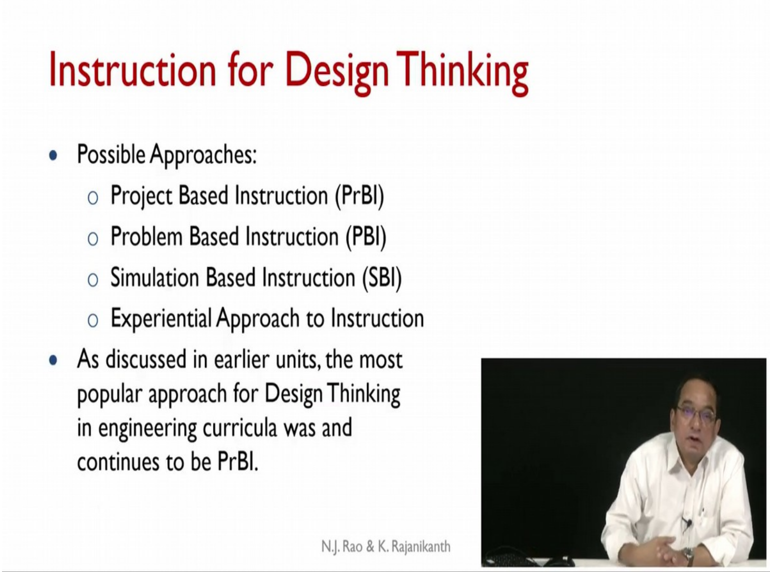

Some of the possible approaches for design thinking would be project based instruction, problem based instruction, simulation based instruction, and experiential approach to instruction. (All these four approaches - we have discussed in the earlier units and we saw the advantages and limitations of these approaches and we also looked at the specific situational context, which will necessitate adapting these approaches to specific institutes and specific contexts.)

(As discussed in these earlier units) the most popular approach for design thinking in engineering curricula was and continuous to be project based instruction, because that activity most closely resembles the activity that engineers engage in during their professional practice.

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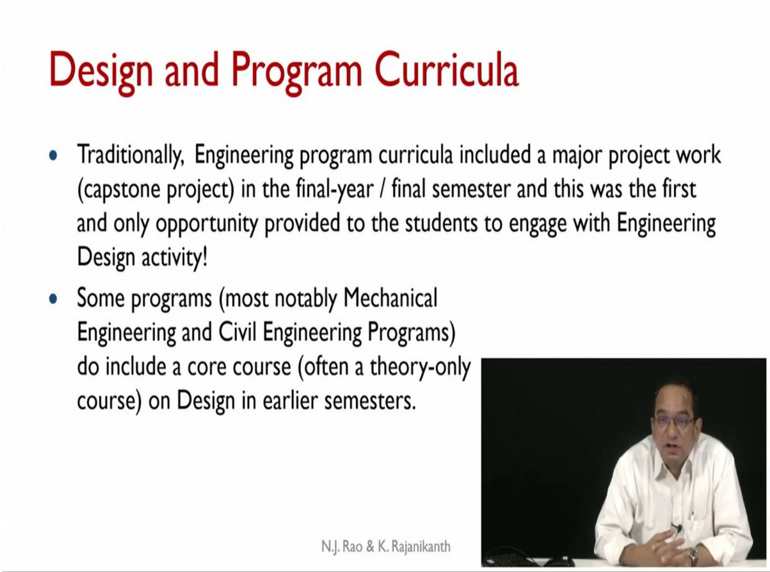

Traditionally engineering program curricula included a major project work in the final-year or final semester and this was the first and only opportunity provided to the students to engage with engineering design activity. The CDIO framework generally calls this as a capstone project, but in India the more common terminology is to simply call it as the main project or final-year project.

Some programs, most notably mechanical engineering and civil engineering programs, do include a core course - often a theory-only course - on design in earlier semesters; typically either in 4th or 5th or 6th semester. Many institutes do have a course, but this is not common across all the disciplines. Quite often mechanical engineering and sometimes civil engineering do include such a course, but often it is theory only course; though in some institutes, they do have some laboratory component, where they generally teach the use of some software packages which are useful in the design activity.

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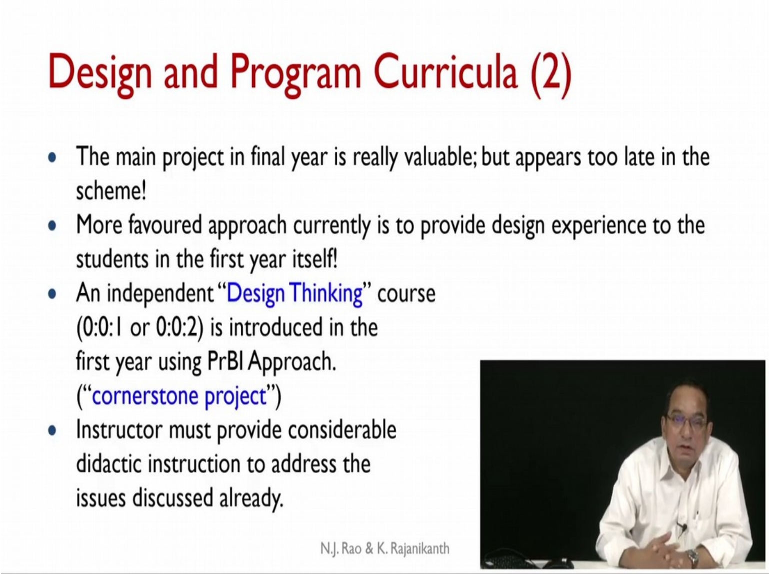

The main project in final year is really valuable. It is the first time the students engage in synthesis activity. It gives them the real engineering design experience. But it appears too late in the scheme, either in the final year or final semester. In this context, the idea of some of the institutes to give an option to the students to do additional theory courses in place of a project, probably is not a very good move.

A more favoured approach currently is to provide design experience to the students in the first year itself. Often the idea is that the engineering students, who join the program, do get exposure to engineering design only in the final year! By that time, some of the students do get demotivated. In the entire first year, there is no exposure to what actually engineers do. The thinking has been that we should expose the students to the engineering design activity right in first year.

An independent design thinking course - either 0 theory, 0 tutorial, 1 lab or 0 theory, 0 tutorial, 2 lab units can be chosen - and is introduced in the first year itself using project based instruction approach. Again CDIO framework calls this as cornerstone project, but in India we are more used to calling this as simply a design thinking course.

Instructor must provide considerable didactic instruction to address the issues discussed already because the students are just in first year. And many of the issues that we discussed, which are the characteristics of engineering design thinking, may require certain explicit didactic instruction. Though the credits for theory are 0, usually the instructors do provide certain additional instruction to the students.

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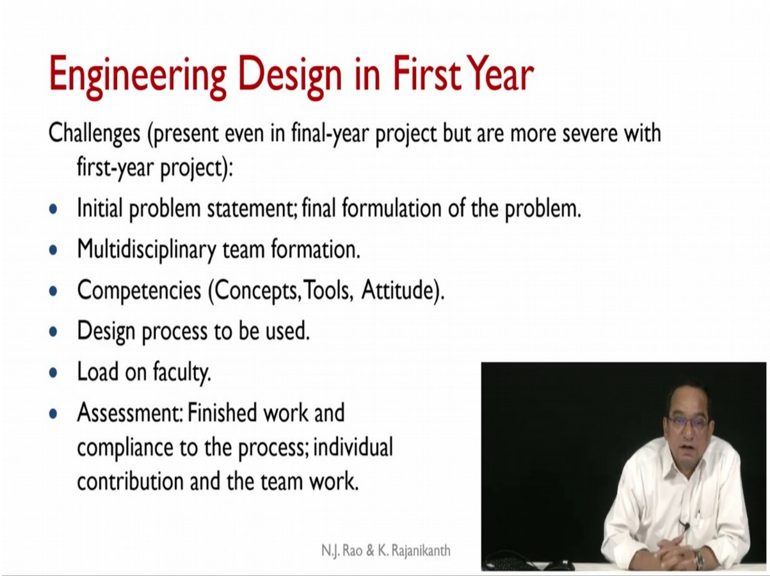

The challenges which are present particularly in first-year - these challenges exist even in final-year project - but they become more severe with first-year project, because the students as such are not yet exposed to domain specific courses or engineering courses much; may be one or two elementary introductory courses in mechanical engineering, civil engineering and a computer programming course.

Problems are that how do we formulate the initial problem? How do we formulate the problem in engineering terms from the statement given in a fuzzy way using natural language? How does the initial formulation take place? Finally, how does it get a specific problem in engineering terms?

How do we train the students in moving from the fuzzy statement of the problem in a natural language to highly specific statement in engineering terms of a completely specified problem? How do we form multidisciplinary teams? The competencies required, some basic design concepts, tools, attitude; even some machinery and some software packages, some elementary/basic exposure would be required. We need to provide some basic training to the students so that they get some minimal competencies to carry out the project.

The design process to be used, the specific process steps, need to be made very clear and students must be trained in those process steps. Obviously, most of the institutes have a very large number of students in the first year. So, handling the project teams (which would be very large in number) would require considerable time and effort from the faculty side. The load on the faculty is going to be fairly substantial and we need to plan to have these resources adequate in number.

Assessment is also a challenge! We need to assess not only the finished work, but also the compliance to the process, to what extents the students have understood and are following the design process. We also need to evaluate the final product and we need to make clear distinction between the individual contribution and the team work. The students also must understand that they will be evaluated individually as well as a team. These things must be really addressed by the designers of the curriculum.

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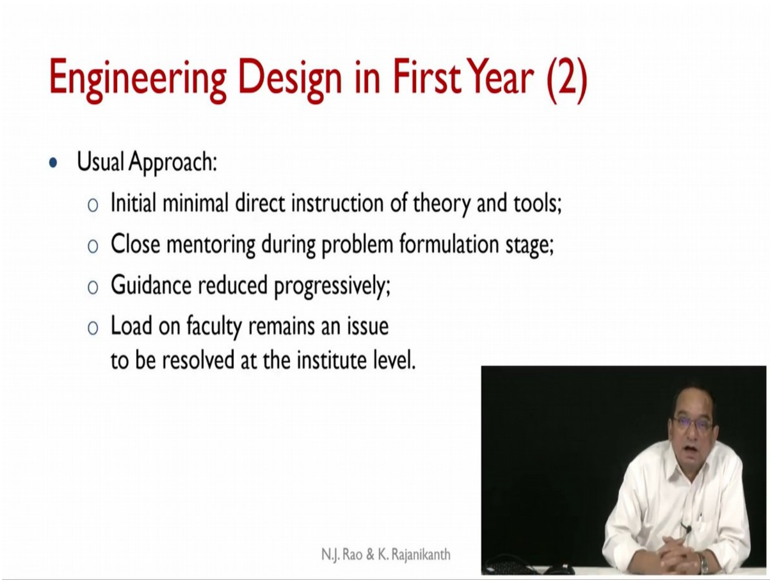

The usual approach for this is that initially minimal direct instruction of theory and tools is provided (as I mentioned.) This exposure is required to provide certain minimal competencies to the students. Close mentoring during problem formulation stage also happens, because they need to translate the fuzzily stated problem into precise engineering terms and this is again a load on the faculty.

Guidance is reduced progressively, so that students get adapted to thinking independently and in groups of their own without the kind of hand holding by the faculty, which happens in the initial stages. Load on the faculty remains an issue to be resolved at the institute level.

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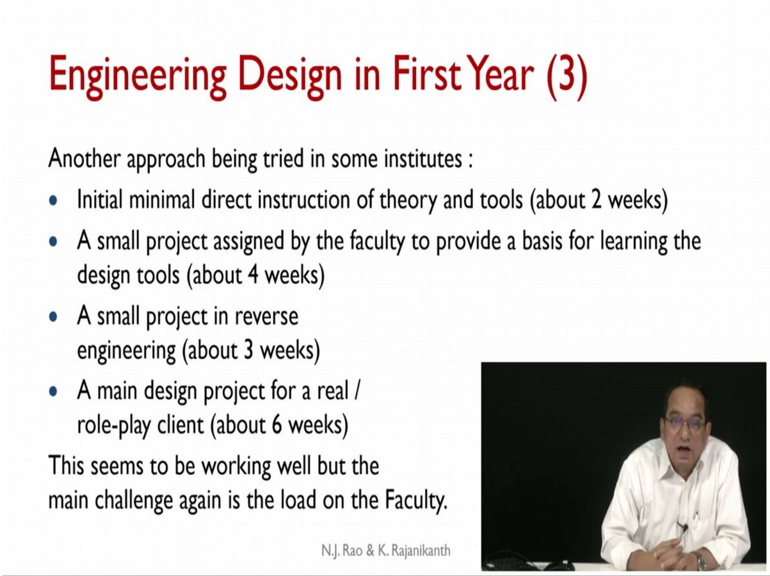

Another approach being tried in some institutes (which is still not very popular in India, but some institutes are trying and this has been tried abroad also in some institutes): initial minimum direct instruction of theory and tools - about 2 weeks. This would include certain exposure to the software packages as well as the machinery and the tools to be used. About 2 weeks.

Then a very small project assigned by the faculty to provide a basis for learning the design tools - this could be about 4 weeks. This is more exploratory in nature to make the project teams comfortable with the idea of working in a team on a design problem; so to expose the students to design thinking.

Then a small project in reverse engineering - about 3 weeks - a completed product is given and the students do the reverse engineering activities, in order to understand how the product was synthesized. This will be usually followed by some kind of a discussion, where the students express their comments and opinions about the design process followed to arrive at this final product.

Then a main design project for a real or a role-play client! This will be the real culmination of all this training activity for about 6 weeks. Some institutes have taken the bold step of having this project done for a real client. Usually the client is someone from a local community! So the students are being sent to visit the local communities to understand their problems, then come back and discuss with the faculty and come out with a formulation of a problem whose solution would have some bearing on the local community.

Of course where such a thing is not possible, the instructor can play the role of a client or sometimes, some of the project teams play the roles of clients! But some exposure to the idea of eliciting requirements from the client must be given. Most of the institutes do have a process step of eliciting the requirements. The students must be trained in this particular process step. That is how the students get an experience in engineering design thinking and design during the first year itself.

This seems to be working well. But the main challenge again is the load on the faculty. The number of project ideas to be generated, the resources to be provided, the time to be spent in mentoring the student teams and the time spent in assessment and evaluation, represent substantial load on the faculty.

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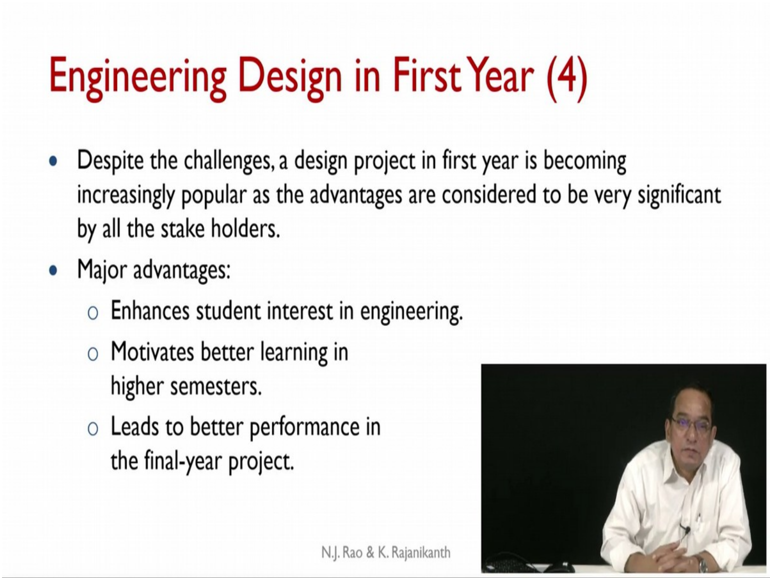

Despite these challenges, a design project in first year is becoming increasingly popular as the advantages are considered to be very significant by all the stake holders. The faculty, students, parents, even the industry find it very, very attractive to have the students exposed to engineering design and engineering design thinking right in the first year. They find that this enhances student interest in engineering and motivates better learning in higher semesters.

They are able to better see the context of the courses studied at higher semesters and they are able to relate those courses to their professional requirements in a better fashion. It leads to better performance in the final-layer project. They already have had an experience of doing a project; thinking in an engineering designer's way in first year and that makes it possible to produce better performance in the final year project. This in turn enhances their placement opportunity and industry also finds them to be more employable.

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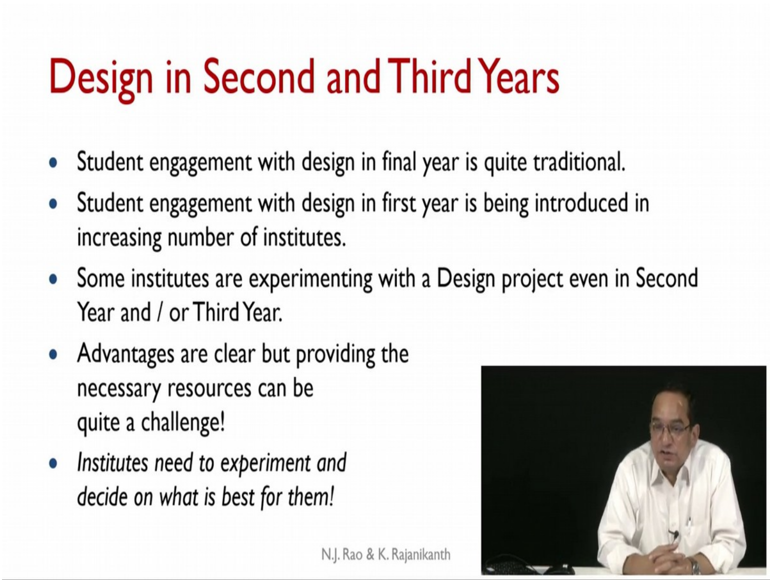

Some institutes, of late, have started experimenting with the idea of design thinking in second and third years also. The final year was always common, first year - it has been tried for quite some many years and it is continuing, but of late, some institutes are trying to introduce design thinking course, even in second year and third year. That means there is a sequence - a progression of design thinking courses right from first year through final year.

Student engagement with design in final year is quite traditional; engagement with design in first year is being introduced in increasing number of institutes. But some institutes are experimenting with a design project even in second year and/or third year; some are trying it in both the years, some are trying it in third year, some in second year.

The focus on giving this kind of exposure to the students, providing this kind of design experience to the students is becoming more and more popular.

Advantages are clear. But providing the necessary resources can be quite a challenge. Institutes need to experiment and decide on what is best for them, given their specific situational requirements. They need to determine what kind of mixture of these activities would be working best for them. There is nothing like one unique solution which can be adopted by all institutes.

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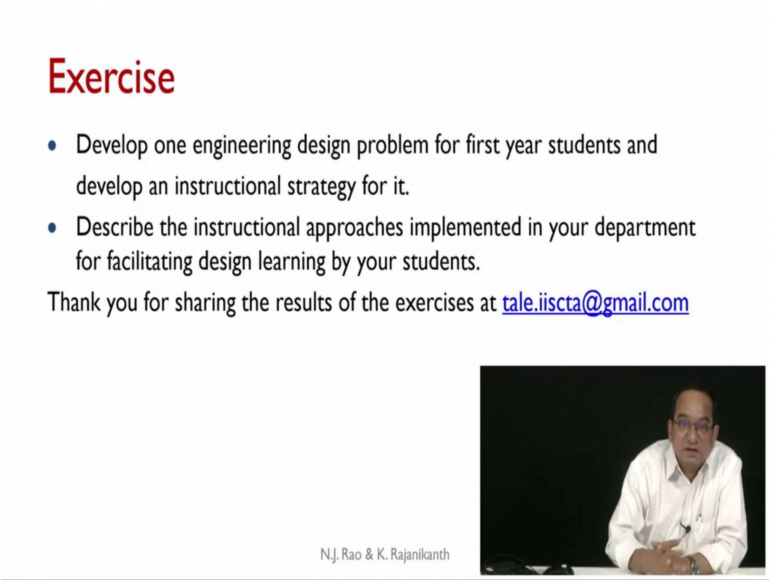

Exercise: 1) Develop one engineering design problem for first year students and develop an instructional strategy for it. 2) Describe the instructional approaches implemented in your department for facilitating desired learning by your students.

Thank you for sharing the results of the exercise at tale.iiscta@gmail.com.

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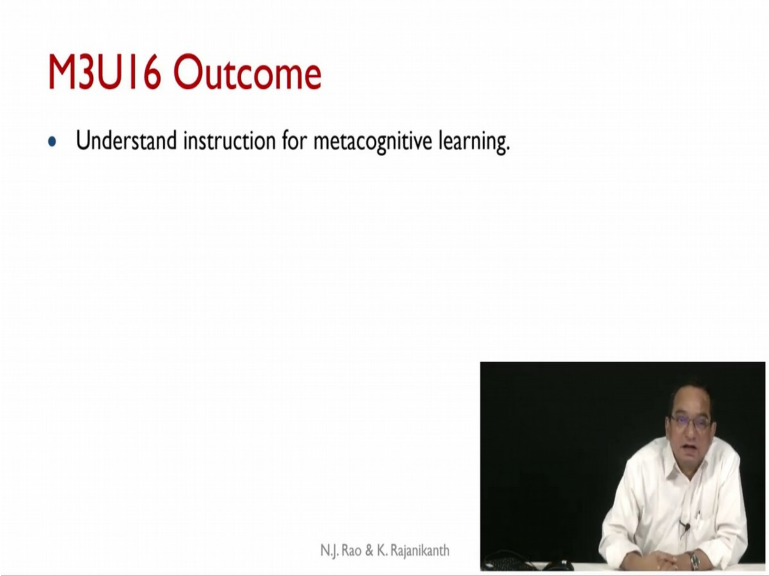

In the next unit, we will understand instruction for metacognitive learning and how do the instructors take care of the metacognitive aspects of learning - an extremely important aspect of student learning which has tremendous influence on student learning.

Thank you.